High Response Dew Point Measurement System for a Supersonic Wind Tunnel

Philip Z. Blumenthal
NYMA, Inc.
Brook Park, Ohio

February 1996

High Response Dew Point Measurement System for a Supersonic Wind Tunnel

Philip Z. Blumenthal
NYMA, Inc.
2001 Aerospace Parkway
Brook Park, OH 44142

KEYWORDS

Dew Point, Humidity, Hygrometer, Supersonic Wind Tunnel

ABSTRACT

A new high response on-line measurement system has been developed to continuously display and record the air stream dew point in the NASA Lewis 10x10 Supersonic Wind Tunnel. Previous instruments suffered from such problems as very slow response, erratic readings, and high susceptibility to contamination. The system operates over the entire pressure level range of the 10x10 SWT, from less than 2 psia to 45 psia, without the need for a vacuum pump to provide sample flow. The system speeds up tunnel testing, provides large savings in tunnel power costs and provides the dew point input for the data-reduction subroutines which calculate test section conditions.

INTRODUCTION

Lewis's 10x10 SWT produces air speeds ranging from Mach 2 to 3.5 (1320 to 2311 mph) in the test section by expanding the air through a flexible nozzle. This expansion can cause any moisture in the air to be cooled below the dewpoint temperature and thus condense out in the test section. The condensed moisture appears as a dense fog in the tunnel which prevents the experimental model from being observed through the tunnel windows. The condensation also causes changes in the local Mach number and other flow conditions such that the data taken may be erroneous.

To remove this moisture, the atmospheric air passes through beds of activated alumina in an 82 ft high air dryer building before it enters the tunnel. This dryer can absorb moisture at the rate of 1½ tons per minute until the beds are saturated. Since the amount of time the tunnel can run with dry air depends on the test section conditions and the outside temperature and humidity, the tunnel operator must monitor the dewpoint throughout the run.

Until the new electronic system was developed, the tunnel operator used an Alnor Dewpointer, a manually operated instrument which required a slow trial-and-error process to determine the moisture content of the air stream. For each reading, the operator would use a hand pump to pressurize a sample

1

of air in a observation chamber, wait for the sample to stabilize, depress a valve to produce a sudden expansion to atmosphere, and observe whether a fog began to form. If the fog did not appear, the process was repeated again. If the dew point reading finally obtained was not suitable for taking data, the tunnel conditions were changed and another manual measurement operation was performed. Because of the tunnel drive power consumed during the several minutes required to obtain each reading, this procedure was very costly.

Additionally, at tunnel total pressures below atmospheric, this fog chamber instrument required the pressure in the sample line to be raised above atmospheric using a large water-cooled, pneumatically-operated pump. This pump was very trouble-prone and needed to be disassembled often to repair water leaks and seal failures. For very high altitude tunnel tests the pump was not usable at all.

Numerous attempts were made over a thirty year period to develop an electronic replacement for the fog chamber unit, but none of the new instruments provided data that was dependable and that agreed with the manual unit. It was found that in this application the response to dew point changes was very slow, the readings were erratic and the sensors were easily contaminated. Therefore, a study was initiated which determined the causes for these problems and which resulted in the successful implementation of a high response on-line tunnel dew point measurement system.

APPROACH

Since moisture/humidity instruments are manufactured by more than 80 companies in hundreds of models it would not be practical to independently conduct an evaluation of all of them. To obtain user's first hand experience with dew point measurement in similar aero test facilities, test engineers were contacted at NASA Ames, NASA Langley, and Arnold Engineering Development Center. These conversations provided a great deal of information about the problems experienced in past attempts to measure tunnel moisture and about the instruments and systems presently used.

Most of the wind tunnels surveyed used a chilled mirror moisture analyzer. However, as many as three of these instruments were needed to provide reliability and redundant data to detect inconsistencies, and special attention must be given to periodic cleaning of the mirrors.

A chilled mirror instrument and an aluminum oxide sensor had previously be installed in the 10x10 dew point system but neither were able to be used because of slow response, poor reliability and inconsistent results. Therefore, a recommendation was made to management to lease a new type of dew point instrument for evaluation. This unit uses a silicon chip based sensor which has very rapid response to humidity changes and is quite insensitive to sample flow rate. It had been successfully used at Langley to measure flow moisture content in several hypersonic wind tunnels (Ref. 2)

DEW POINT INSTRUMENTATION DESCRIPTIONS

The following instruments were used in this investigation:

2

Fog Chamber Unit

This unit was an Alnor Model 7000U Dewpointer which uses a hand pump to force a sample of the tunnel air into an observation chamber at a pressure above atmospheric. After the sample stabilizes, a valve is depressed and the gas is rapidly exhausted to the atmosphere with a sudden expansion and simultaneous cooling of the gas that remains in the chamber. If the cooling is sufficient to bring the temperature of the gas down to or below the dew point, water vapor will condense in the form of a fine mist or fog which can be seen through a lighted observation window. From the pressure ratio (read from a U-tube) when the slightest fog is seen and the initial air temperature (read from a thermometer) the dew point is determined with a circular slide rule calculator. The quoted accuracy of the Alnor is ±5°F, but errors of greater than 20°F can occur at a dew point of -20°F if the air sample contains insufficient dust to act as nuclei for the cloud droplets to form and/or if insufficient settling time is allowed before the sample is exhausted.

Aluminum Oxide Sensor

This sensor contains an aluminum wire coated with a hygroscopic dielectric layer and finally covered by a film of porous gold. The gold film and aluminum core form the plates of a capacitor which is excited with 60 Hz. Water vapor molecules which enter the dielectric layer are restricted due to the extremely small size of the pores and condense into liquid water. This high dielectric constant of water changes the capacitance of the sensor which is measured by the analyzer. The instrument used has a range of -112°F to -4°F with a specified accuracy of ±5.4°F.

Chilled Mirror #1 and Chilled Mirror #2

The chilled mirror technique incorporates a multistage thermoelectric cooler that precisely regulates the surface temperature of a metallic mirror surface in order to maintain a threshold formation of dew. The mirror temperature, measured with a platinum resistance thermometer, is an accurate indicator of the dew or frost point. The dew layer is optically detected through use of a high intensity light emitting diode (LED) and a photodetector that monitors the LED light reflected from the mirror. A separate LED/photodetector combination is used to compensate for any thermally induced changes in the optical components. The sensor for Chilled Mirror Unit #1 uses a two-stage cooler that provided a range of -32°F to +200°F. Chilled Mirror Unit #2 uses a sensor with a four-stage cooler and has a measurement range of -85°F to +95°F. The "typical" accuracy given for both units is ±0.36°F.

Chilled-Mirror #3

This instrument uses a microprocessor to monitor and control not only the primary mirror system but also to monitor a secondary dry mirror system to automatically compensate the primary mirror system for changes in mirror reflectivity caused by particulate matter buildup, changes in receiver sensitivity, or changes in other factors that are common to both mirror systems. Chilled mirror unit #3 had a dew point range of -100°F to +167°F and a "nominal" accuracy specification of ±0.36°F.

Silicon Sensor

This instrument was a MCM Model 700 Dewluxe 20 Hygrometer which was developed in England by

Moisture Control and Measurement Ltd (MCM) and is distributed in North America by Stephens Analytical, Inc of Montreal. The sensing element of the MCM is a proprietary moisture detector built on a low-mass silicon chip. A closed-loop temperature control eliminates ambient temperature error between -40°F and +113°F. The sensor operates satisfactorily between flow rates of 50 to 1500cc's/min, or even static conditions at an operating pressure from vacuum to 4000 psig. The "push-purge" feature heats the sensor to a high temperature to remove moisture and hydrocarbon vapor contaminants and allows on-line verification of instrumentation operation within two minutes. The sensor responds to a step change in moisture from +64°F to -76°F in less than 1 minute with a sensitivity of 0.002°F. The unit was ordered with a bridge box which provides a cable length of 100 meters between the sensor and the readout unit. The range of this unit is -60°C to 0°C (-76°F to +32°F) with an accuracy of ± 3°C.

TEST PROCEDURE

Initial testing was performed with the silicon sensor and the aluminum oxide sensor installed in the sample line just downstream of the dewpoint pump in the 10x10 bellmouth area. Readings from these units during tunnel runs differed substantially from that taken with the Alnor. In order to investigate the reasons for these differences, a test setup, shown in Figure 1, was installed in the Control Room. This rig allowed changes in flow rates, flow paths, and tubing size to be varied in order to determine the individual influences of these parameters. Except for the MCM, which is not sensitive to flow, the instruments were connected in parallel to the sample line with a needle valve and rotameter in each leg to set the sample flow for the optimum response of each instrument. The output of the MCM was converted and displayed by the tunnel data acquisition system (ESCORT D+) in corrected dew point (not frost point, as is explained later).

Data was taken both on-line during tunnel runs and also off-line by varying a mixture of service air and dry nitrogen over the dew point range. The aluminum oxide instrument appeared to drift excessively and required removal of the sensor and resetting to the calibration mark on a daily basis to maintain calibration. Therefore, testing with this unit was terminated early in the study.

TEST RESULTS

The test data provided a much clearer understanding and insight into the causes for the problems experienced in previous attempts to replace the Alnor with an on-line instrument. These causes are described in the following synopsis:

Behavior of Chilled Mirror Instruments

A comparison of readings from the three chilled-mirror instruments verses the MCM silicon sensor is shown in Figure 2. The data was corrected for a +1.5°F bias shift in the MCM that was determined after extensive calibration. Chilled Mirror #1 saturates at about -34°F because that is the lower limit of its sensor cooler. Although most of the data from the chilled mirror instruments fell very close to the MCM, there were some anomalies seen in all three instruments at various times during the test. One of these problems was due to the very slow response of the chilled mirror units. Even though at least 15 minutes settling time was allowed before readings were taken after each change in dew point

level, it could not be assured that these instruments had stabilized. For example, in Figure 2 it is seen by the dotted lines that the #1 unit only reached -13°F instead of -43°F even though 37 minutes had elapsed since the dew point had been changed from the previous level of -11°F. One report (Ref. 1) indicated that chilled-mirror units require up to 4 hours to stabilize under dry conditions.

The other problem, as indicated by the other dotted lines in Figure 2, was the erratic behavior that was occasionally exhibited by the Chilled Mirror Units #2 and #3 after several days of testing. In these cases, the instrument would suddenly begin reading erroneous values without any of the front panel warning lights indicating that the readings were wrong. Only after the unit had been turned off for hours would the readings return to normal. Some of the explanations for this problem reported by other researchers (Ref. 3,4) is that either some tiny pockets of water may get trapped inside the fittings or recesses of the sensor cavity or that dust particles, once in contact with a wetted mirror surface will remain there and act as moisture-storing sponges which produces an artificially high measurement. However, no moisture was seen when the sensor housing was opened for examination.

Dew Point/Frost Point Ambiguity

When a chilled-mirror instrument is measuring a sample flow with a dew point below 32°F the water on the mirror surface can be ice or supercooled liquid. Generally, it is in a liquid state for a short period of time before it freezes and a crystal lattice, much like a snowflake, begins to grow on the mirror. For a given gas sample with a fixed vapor content, the temperature at which a surface of ice (Frost Point) must be maintained to be in equilibrium with the water vapor is slightly higher than that for water (Dew Point). Tables which list the values for Dew Point vs Frost Point are included in most humidity handbooks (such as Ref. 6). Although the period of time required to normalize the frost can vary greatly, it is generally accepted that the value read by the chilled-mirror instruments below 32°F is the Frost Point rather than the Dew Point. The silicon sensor instrument is also calibrated to read the Frost Point value.

Since the Alnor depends on viewing a fog produced by condensation of the moisture in an unstable supercooled expansion of the sample, it is calibrated in Dew Point. Since the Alnor readings were used as the standard for operating the 10x10 in the past, the silicon sensor readings were converted by the Escort program from Frost Point to Dew Point. This correction helped to provide closer agreement between the Alnor and the silicon sensor readings.

Alnor Wait Time

While the instructions in the old Alnor Dewpointer Manual (11/72) stated that 10 to 15 seconds should lapse after pumping the sample into the chamber before pushing down the operating valve, the new Alnor Manual (4/90) says to wait **at least 60 seconds** for the gas to cool after it has been pumped, and in some cases the waiting time may have to be extended to **two or three minutes.** The 10x10 tunnel operators generally wait from 0 to 15 seconds after pumping each sample because of the need to take a reading as quickly as possible during a run. Figure 3 shows the effect of wait time on data taken during a recent tunnel test. Alnor read about 11°F lower than the MCM with a wait time of 0 seconds, 6°F lower with a wait time of 15 seconds, and about 1°F lower with a 30 second wait time. This helps to explain the differences seen between the Alnor and the on-line instruments used in the past.

5

TUNNEL SAMPLE SYSTEM DESIGN

The 10x10 bellmouth static pressure can vary from less than 2 psia to greater than 45 psia for various test conditions. When this pressure was below atmospheric, a large water-cooled pneumatically-operated pump was needed to supply the tunnel flow sample to the Alnor. The MCM, however, can operate at tunnel ambient pressure over a wide flow range if the pressure level is measured and the output is converted to an equivalent dew point at atmospheric pressure. This can be performed in real-time by ESCORT D+ using Dalton's Law of Partial Pressures and the standard Smithsonian Meteorological Tables to relate the measured dew point and sample line pressure to an atmospheric dew point reading.

Two completely independent MCM hygrometer systems are used for the 10x10 dew point measurements. A schematic of one of the tunnel air sampling systems is shown in Figure 4a. The inlet pressure level is measured with a Setra Model 204 pressure transducer and the MCM flow rate is monitored with a rotameter. A sensor bypass line provides for an increase in the sample mass flow without causing too great a flow through the sensor. Prior to tunnel operation the service air purge system is used to flow dry air through the dew point sensor and the sample system. After the main drive compressor has reached operating speed and the air dryer inlet valve has begun to open to dry out the tunnel, the system is switched (through solenoid valves) to the inlet tube in the tunnel bellmouth and the rearward facing exhaust tube in the second throat (the converging/diverging section downstream of the test section). This utilizes the pressure difference across the test section to produce the sample flow at all pressure levels.

IN-SITU CALIBRATION SYSTEM

Although the MCM hygrometers have displayed good stability, it is imperative to provide a periodic calibration of the units with traceability to national standards every six months or less. However, whenever the units had been removed from the sample system for calibration and subsequently reinstalled, very small leaks have been found in the fittings which are very difficult to locate and repair. Since the tunnel air sample is usually below atmospheric, moisture will migrate into the sample system if it is not completely leak free.

The in-situ calibration system shown in Figure 4b. uses a General Eastern Model DPG 300 Dew Point Generator to provide a wide range of stable dewpoint conditions in the sample system without removing the MCM sensors. As shown in this figure, the DPG 300 utilizes a divided flow/saturation system in which the dry gas is regulated and split into two streams. One is saturated, the other is kept dry. The two streams are blended together with three precision flowmeters. A fourth flowmeter controls and monitors the output flow rate. Mixing ratios of dry gas to wet gas of 100,000 to 1 can be accurately maintained allowing generated dewpoints from -80 °C to +15 °C to be set precisely. A nitrogen cylinder is used to supply the dry gas to assure that a constant dry gas dew point is maintained during the entire calibration period. The chilled mirror instrument used as the transfer standard for the calibration is provided as an on-site calibration service by the Lewis Cal Lab.

SUMMARY

Until a reliable high response system was developed to continuously measure the moisture content in the 10x10 tunnel airstream it was necessary to sample the dew point occasionally using the manually operated Alnor unit. This method consumed a large amount of run time since the operator had to use a trial and error system to obtain a reading and then change tunnel conditions to get an acceptable dew point for taking data. The silicon sensor hygrometer has been shown to be a high response, accurate, and dependable instrument for providing real-time dew point readings under wind tunnel operating conditions.

With the use of the new on-line silicon sensor system in dew point surveys during a new test section calibration test conducted in February, 1995 the test section Mach number and total pressure recovery dependence on the air stream dew point were determined. This resulted in the development of a new tunnel condition subroutine to compute the test section conditions using a mathematical model derived from the calibration data. This subroutine uses the direct inputs from the 10x10 dew point hygrometer system to provide real-time calculation and display of the corrected test conditions.

ACKNOWLEDGEMENT

REFERENCES

1. Mehrhoff, T.K., "Comparison of Continuous Moisture Monitors in the Range of 1 to 15 ppm," Rev. Sci. Instruments, Vol. 56, No. 10, October, 1985.

2. West, J. W., "A System to Measure Flow Moisture Content in Hypersonic Wind Tunnels," NASA TM 107628, April, 1992.

3. Cooper, F. G., "Dew Point vs. Frost Point," Sensors, October, 1991.

4. Buck, A. L., "Hygrometry in the Real World," Sensors, October, 1991.

5. Blumenthal, P.Z., "10x10 Dew Point System Calibration Plan", Aeropropulsion Facilities & Experiments Division, Preliminary Information Report #32, NASA Lewis Research Center, Cleveland, OH, October, 1994.

6. General Eastern Instruments, "General Eastern Humidity Handbook", Document No. A40103384, May, 1991.
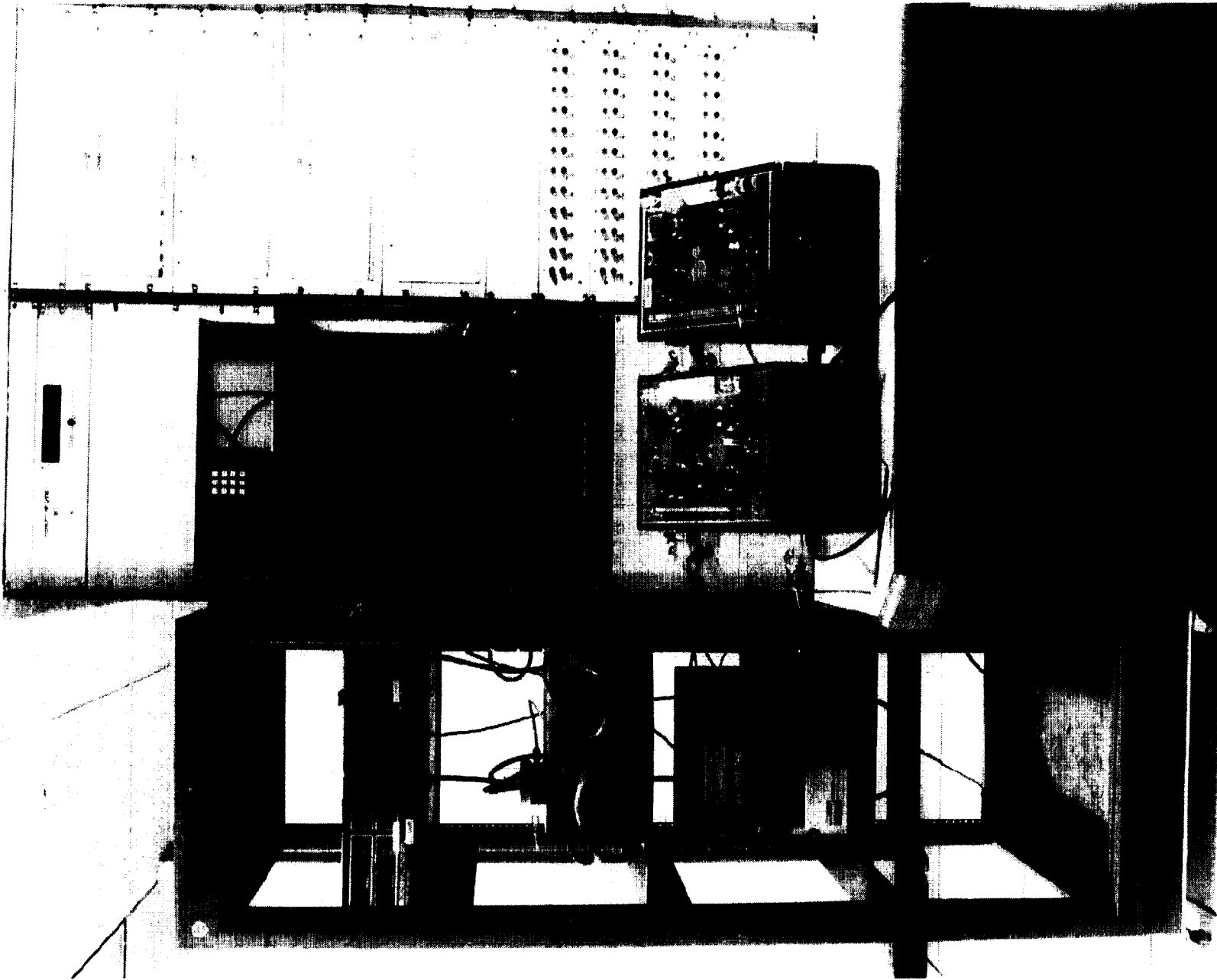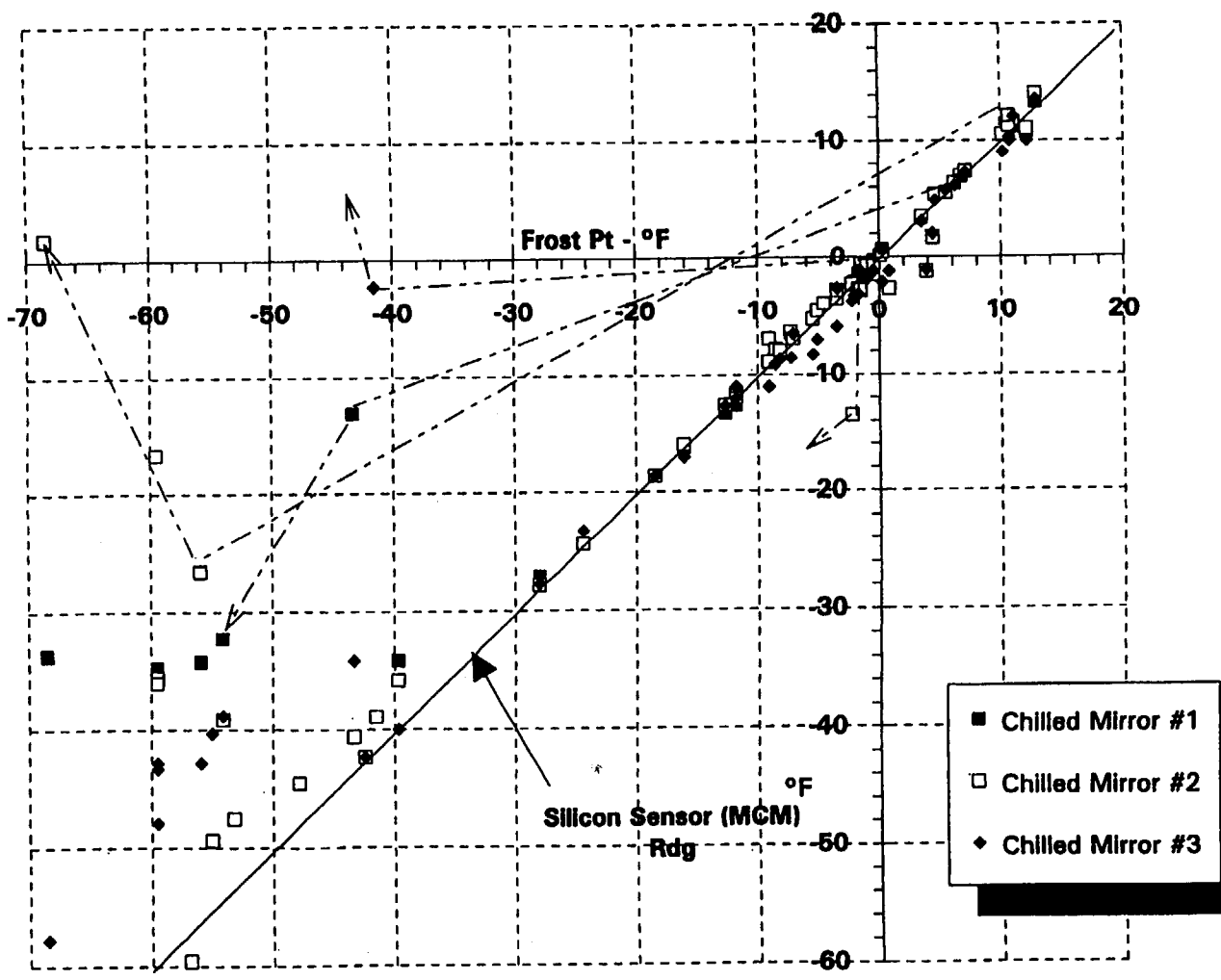
Figure 1. Dew Point System Test Setup.

8

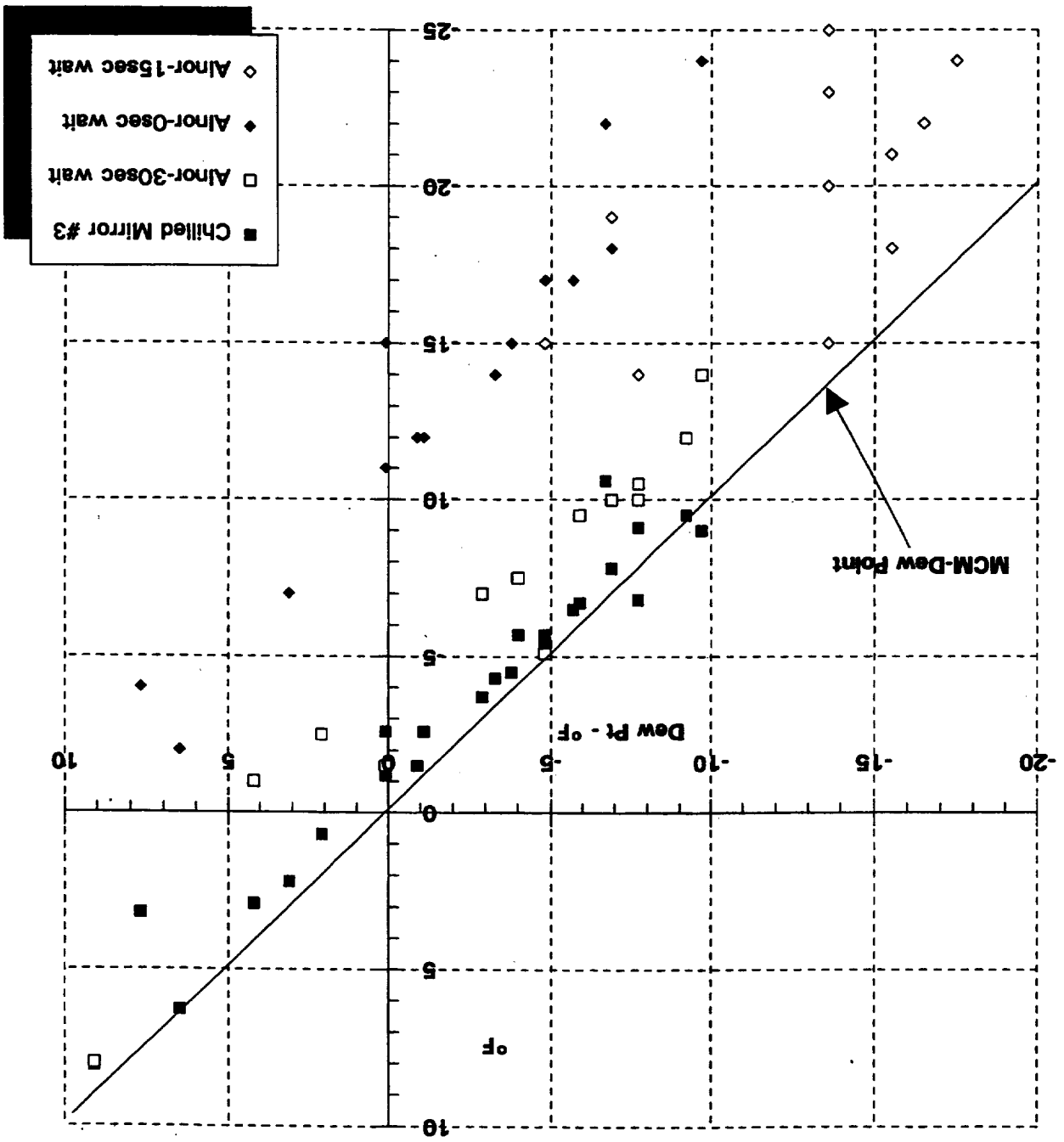**Figure 2. Instrument Frost Point Comparisons.**

Frost Pt - °F

Silicon Sensor (MCM) Rdg

°F

■ Chilled Mirror #1

□ Chilled Mirror #2

◆ Chilled Mirror #3

6
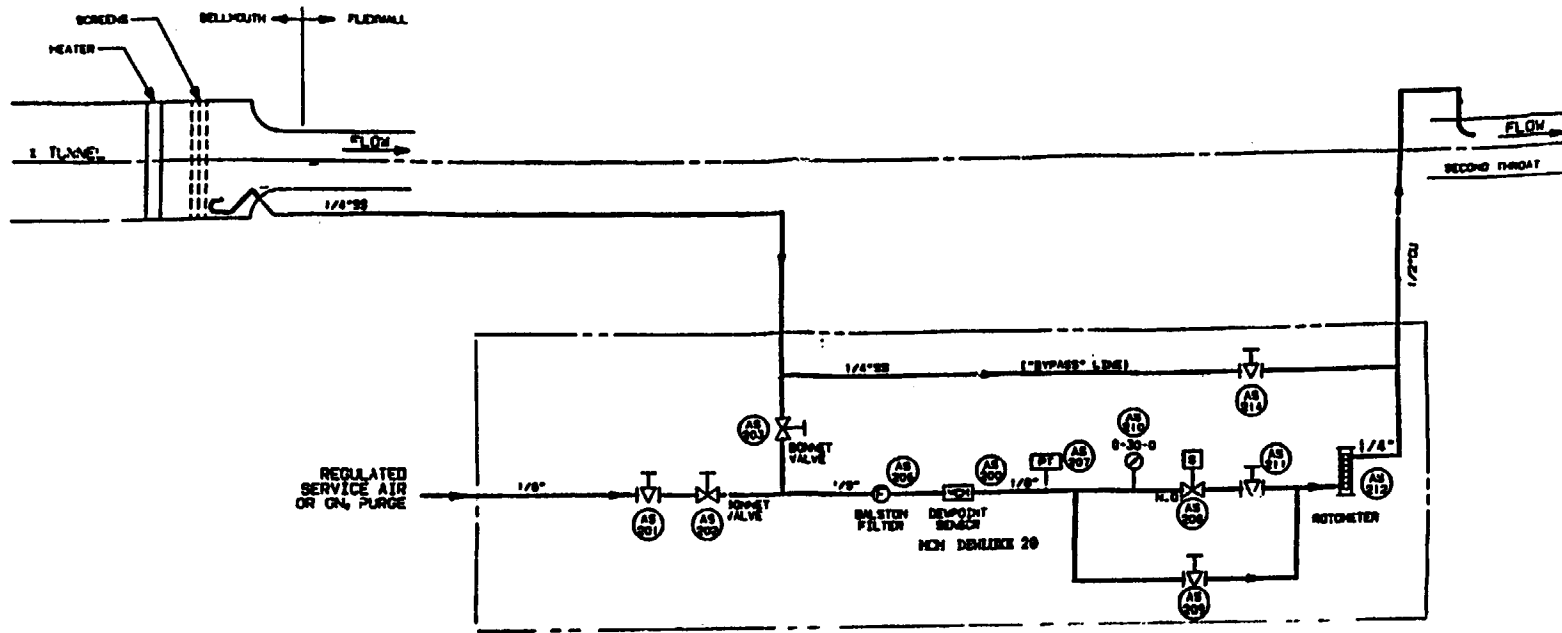
Figure 4a. 10x10 Dew Point Sample System Schematic.
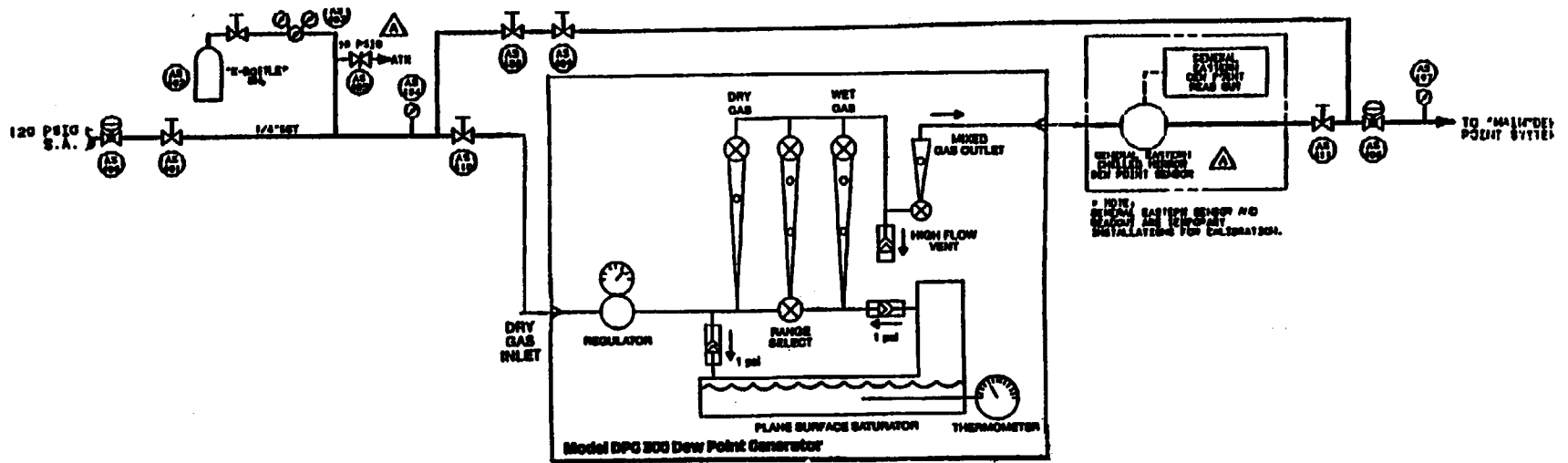
Figure 4b. 10x10 Dew Point Calibration/Purge System Schematic.

11

REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE February 1996	3. REPORT TYPE AND DATES COVERED Final Contractor Report

4. TITLE AND SUBTITLE

High Response Dew Point Measurement System for a Supersonic Wind Tunnel

6. AUTHOR(S)

Philip Z. Blumenthal

5. FUNDING NUMBERS

WU-505-62-82
C-NAS3-27186

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

NYMA, Inc.
2001 Aerospace Parkway
Brook Park, Ohio 44142

8. PERFORMING ORGANIZATION REPORT NUMBER

E-10111

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA CR-198453

11. SUPPLEMENTARY NOTES

Prepared for the 42nd International Instrumentation Symposium cosponsored by the Aerospace Industries and Test Measurement Divisions of the Instrument Society of America, San Diego, California, May 5-9, 1996. Project Manager, Sandra L. Hardy, Engineering Support Division, NASA Lewis Research Center, organization code 2850, (216) 433-2278.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Categories 35 and 09

This publication is available from the NASA Center for Aerospace Information, (301) 621-0390.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

A new high response on-line measurement system has been developed to continuously display and record the air stream dew point in the NASA Lewis 10×10 Supersonic Wind Tunnel. Previous instruments suffered from such problems as very slow response, erratic readings, and high susceptibility to contamination. The system operates over the entire pressure level range of the 10×10 SWT, from less than 2 psia to 45 psia, without the need for a vacuum pump to provide sample flow. The system speeds up tunnel testing, provides large savings in tunnel power costs and provides the dew point input for the data-reduction subroutines which calculate test section conditions.

14. SUBJECT TERMS

Dew point; Humidity; Hygrometer; Supersonic wind tunnel

15. NUMBER OF PAGES

13

16. PRICE CODE

A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	